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RESEARCH MEMORANDUM

THE DAMPING IN ROLL OF ROCKET-POWERED TEST VEHICLES HAVING RECTANGULAR WINGS WITH NACA 65-006 AND SYMMETRICAL DOUBLE-WEDGE AIRFOIL SECTIONS OF ASPECT RATIO 4.5

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
March 29, 1950

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RESEARCH MEMORANDUM

THE DAMPING IN ROLL OF ROCKET-POWERED TEST VEHICLES HAVING RECTANGULAR WINGS WITH NACA 65-006 AND SYMMETRICAL DOUBLE-WEDGE AIRFOIL SECTIONS OF ASPECT RATIO 4.5

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SUMMARY

A free-flight investigation of two rocket-powered model configurations has been made to determine the damping in roll. The models had rectangular wings of 4.5 aspect ratio and were the same except for airfoil section; one configuration had an NACA 65-006 airfoil section and the other had a modified double-wedge airfoil section (6 percent thick). Each model used a rocket motor incorporating a torque nozzle which produced a known torque to roll the model during the accelerated portion of flight. The damping in roll was calculated by balancing the moments acting on the model throughout the accelerating and decelerating portions of flight.

The results of the investigation showed that the damping in roll experienced a sudden decrease for the wing with the modified double-wedge airfoil section while in the transonic speed range and then increased to closely approximate wing-body theory at supersonic speeds. The damping in roll of the wing with the NACA 65-006 airfoil section experienced no sudden change at transonic speeds but fell below supersonic theory. The total-drag coefficient of the models with the wings with the double-wedge airfoil section differed from that of the model with the wings with NACA 65-006 airfoil section in experiencing an earlier drag rise and a decrease with increasing Mach number at supersonic speeds.

INTRODUCTION

This paper includes the experimental results of damping in roll for two rocket-powered research configurations. The models were nominally the same in design, differing only in airfoil section, and

[redacted]

incorporated the canted-nozzle technique described in reference 1. The two configurations had rectangular wings of aspect ratio 4.5 and NACA 65-006 and modified double-wedge (6-percent-thick) airfoil sections. The damping-in-roll coefficient was obtained through a Mach number range of 0.85 to 1.45, with corresponding Reynolds number of approximately 3×10^6 to 6.7×10^6. The flight tests of the models were conducted at the Pilotless Aircraft Research Station at Wallops Island, Va.

SYMBOLS

C_l	rolling-moment coefficient $\left(\frac{L}{qSb}\right)$
C_{l_p}	damping-in-roll coefficient $\left(\frac{\partial C_l}{\partial \frac{pb}{2V}}\right)$
C_{D_T}	total-drag coefficient $\left(\frac{D}{qS}\right)$
D	total drag, pounds
L	rolling moment, foot-pounds
L_p	rate of change of rolling moment with rolling velocity, foot-pounds per radian per second
L_o	out-of-trim rolling moment, foot-pounds
T	torque, pound-foot
$\dot{\phi}$, p	rolling velocity, radians per second
$\ddot{\phi}$	rolling acceleration, radians per second^2
V	forward velocity, feet per second
q	dynamic pressure, pounds per square foot
M	Mach number
A	aspect ratio $\left(\frac{b^2}{S'}\right)$

R	Reynolds number, based on a chord of 8 inches
t/c	airfoil section thickness ratio
b	wing span, feet (diam. of circle generated by wing tips)
S'	total wing area of two wings, 2 square feet (wing panel assumed to extend to model center line)
S	total wing area of three wings, 3 square feet (wing panel assumed to extend to model center line)
I_x	moment of inertia about longitudinal axis, slug-feet^2
M_θ	wing-torsional-stiffness parameter, inch-pound per degree (twisted and measured at wing tip)

Subscripts:

1	sustainer-on flight
2	coasting flight

MODELS

The three models tested were nominally the same as the test vehicles of reference 1 except for wing design. All models of the present test had rectangular wing plan forms of aspect ratio 4.5. Model 1 had an NACA 65-006 airfoil section and models 2 and 3 had a modified double-wedge airfoil section $\left(\frac{t}{c} = 0.06\right)$. Each model had three wings which were constructed of 17S-T4 duralumin and spaced at 120° intervals about a 6.5-inch-diameter wooden fuselage. Figure 1 shows the modification of the double-wedge section, other airfoil data pertinent to these tests, and the complete model configuration.

TEST PROCEDURE

The models were launched from a rail-type launcher at an elevation angle of 70° to the horizontal. Each model was boosted into flight to a Mach number of 0.85, allowed to separate from its booster, and then sustained in flight by an internal rocket motor until a Mach number of 1.45 was reached. Therefore, these tests cover a Mach number range of 0.85 to 1.45 which corresponds to a Reynolds number range of approximately 3×10^6 to 6.7×10^6. (See fig. 2.)

The rate of roll and rolling accelerations were obtained by means of a modified spinsonde (reference 2) contained in the nose of the model. The flight-path velocity and longitudinal acceleration were obtained with a Doppler velocimeter. Atmospheric measurements covering the altitude range of the flight tests were obtained with radiosondes.

ANALYSIS

The damping-in-roll derivative was calculated by balancing of moments acting on the model. The torque nozzle and wing out of trim produced rolling moments which were balanced by the moment of inertia and the damping moment produced by the wing and body. Moment equilibrium for one degree of freedom may be written

$$I_X\ddot{\varphi} - L_p\dot{\varphi} = T + L_o \qquad (1)$$

Resolving equation (1) into coefficient form at the same Mach number for the accelerated (indicated by the subscript 1) and the decelerated (indicated by the subscript 2) portions of flight and solving them simultaneously for damping in roll yields

$$-C_{l_p} = \frac{\dfrac{T}{q_1} - \left(\dfrac{I_{X_1}\ddot{\varphi}_1}{q_1} - \dfrac{I_{X_2}\ddot{\varphi}_2}{q_2}\right)}{\dfrac{sb^2}{2}\left(\dfrac{\dot{\varphi}_1}{V_1} - \dfrac{\dot{\varphi}_2}{V_2}\right)} \qquad (2)$$

The complete analysis of this method for determining damping in roll may be found in reference 1.

The accuracy of C_{l_p}, C_{D_T}, and their component errors for these tests are within the following estimated limits:

T, pound-foot	±2.50
$\dot{\varphi}$, radians per second	±1.00
C_{l_p}	±.04
C_{D_T}	±.002
M	±.010

The preceding estimations are based on individual model calculations. Duplicate models incorporating the same wings increase the accuracy of the data for a specific configuration.

RESULTS AND DISCUSSION

Figure 3 shows the variation of rolling velocity $\dot{\varphi}$ with Mach number of the models for the sustainer-on (accelerated) portion of flight and for the coasting (decelerating) portion of flight. The rolling velocity of model 1, NACA 65-006 airfoil section (fig. 3(a)), did not experience a sudden variation at transonic speeds but models 2 and 3, modified double-wedge sections (fig. 3(b)), showed a sudden dip in rolling velocity between Mach numbers 0.85 and 0.95. The small difference in magnitude of rolling velocity for models 2 and 3 is believed to result from misalinement of the wings during construction.

Figure 4(a) shows the variation of damping-in-roll derivative C_{l_p} with Mach number for model 1 ($A = 4.5$) compared with the damping in roll of a similar model of NACA 65A006 airfoil section wings and aspect ratio 3.71 (reference 1). Also shown are calculated values obtained from unpublished theory which consider wing-body interference. The measured increase in damping with increased aspect ratio is not as much as indicated by theory; however, it should be noted that the difference is within the possible accuracy of the measurements. Neither model having NACA 65 series airfoil section experienced a reduction in damping during the transonic region. Figure 4(b) shows the variation of damping in roll with Mach number as compared with theory for models 2 and 3. These models experienced a reduction in damping in the transonic region and the damping was slightly higher than that of model 1 at the supersonic speeds covered by these tests. This damping approximates the theoretical values at Mach numbers above 1.25.

Figure 5 presents the variation of total-drag coefficient with Mach number for models 1, 2, and 3. In figure 5(a) the increase in total-drag coefficient of the model with wings of NACA 65-006 airfoil section, $A = 4.5$, over that of the model with wings of NACA 65A006 airfoil section, $A = 3.71$, (reference 1) again reveals the influence of aspect ratio. Figure 5(b) presents the total-drag coefficients of models 2 and 3. An earlier rise in total-drag coefficient was experienced by the models having wings with double-wedge airfoil sections than the model with wings having NACA 65-006 airfoil sections. At supersonic speeds within the range of this paper the total-drag coefficients of models 2 and 3 decreased consistently with Mach number, whereas the total-drag coefficient of model 1 remained constant. The general trend of the drag curve for the two models with wings of double-wedge airfoil section compares with that of a double-wedge airfoil section determined by the NACA wing-flow method of reference 3 and an investigation in reference 4.

CONCLUDING REMARKS

The model with NACA 65-006 airfoil section wings experienced no sudden change in damping in roll through the transonic speed region and provided a damping that was somewhat below supersonic theory.

The models with 6-percent-thick modified double-wedge airfoil section wings experienced a sudden decrease in damping in roll at transonic speeds and provided a damping that closely approximated theory at Mach numbers above 1.25.

The models with double-wedge-section wings experienced an earlier drag rise in the transonic region and a greater decrease in drag coefficient at supersonic speeds than the model with NACA 65-006 section wings.

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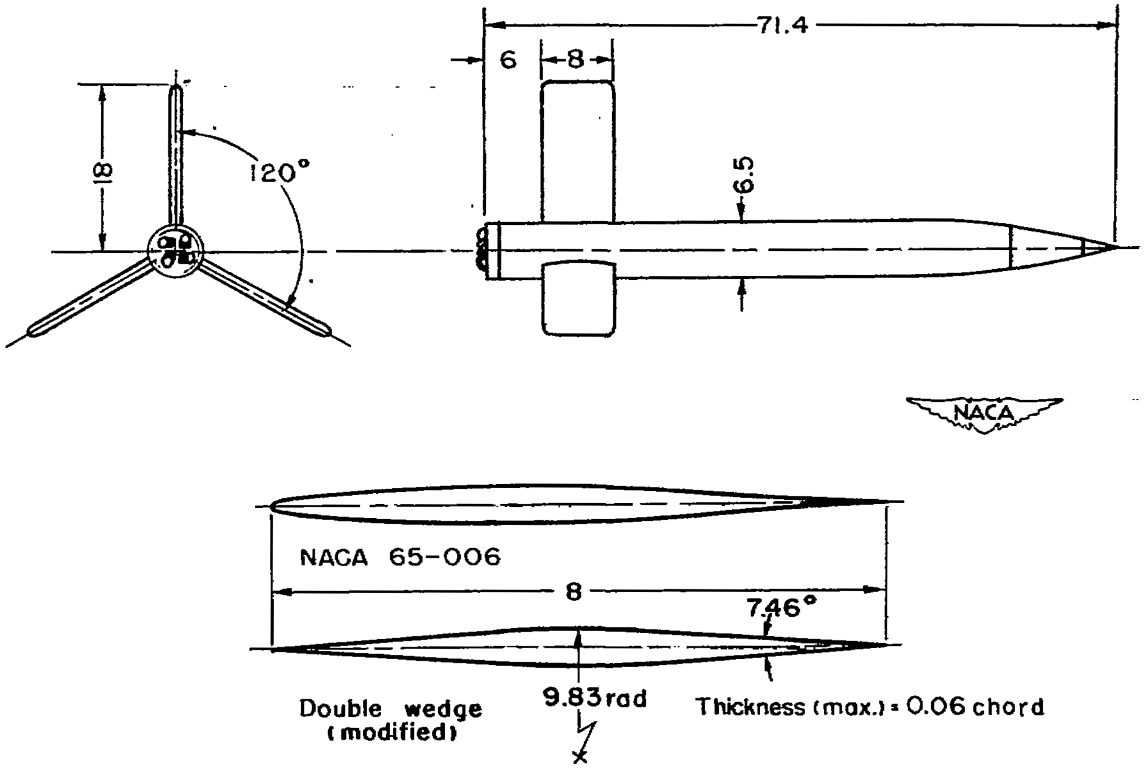


Model	Aspect ratio	Sweep (deg)	Taper ratio	NACA airfoil section	Average M_e at wing tip (in.-lb/deg)
1	4.5	0	1.0	65-006	682
2	4.5	0	1.0	Double wedge	465
3	4.5	0	1.0	Double wedge	485

Figure 1.- Model configuration and airfoil data of the models tested. Sections taken parallel to center line of fuselage. All dimensions in inches.

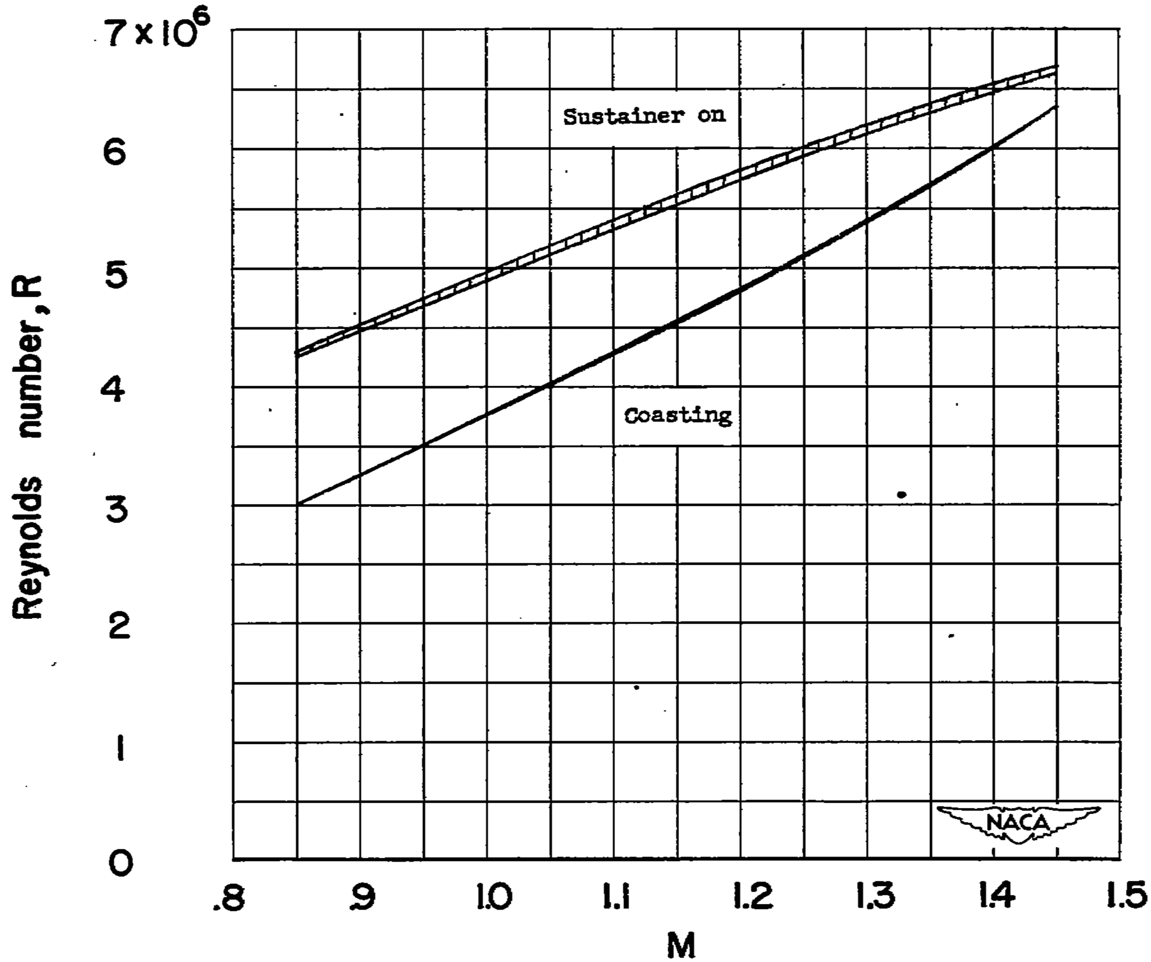
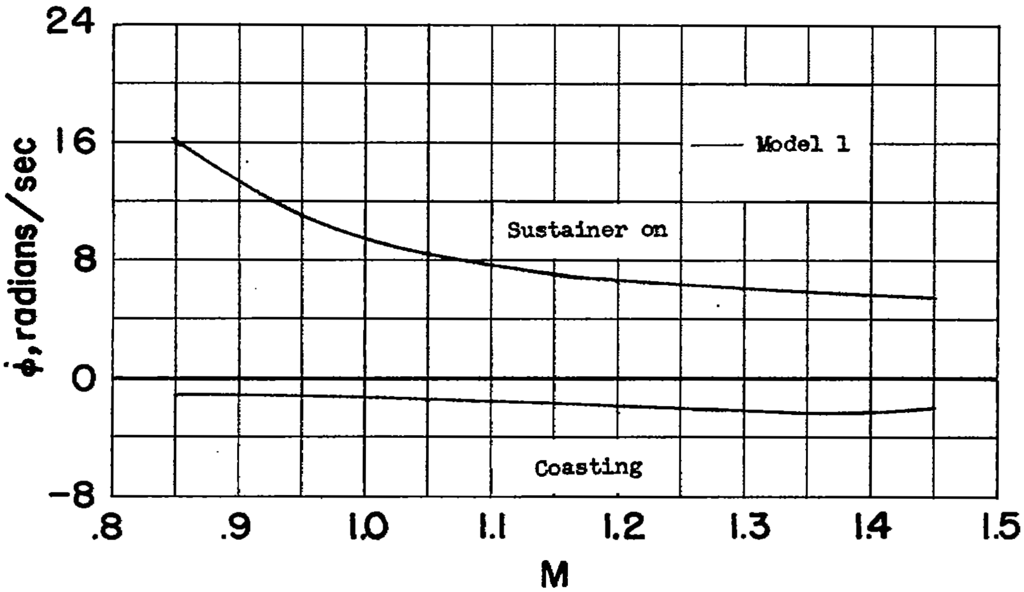
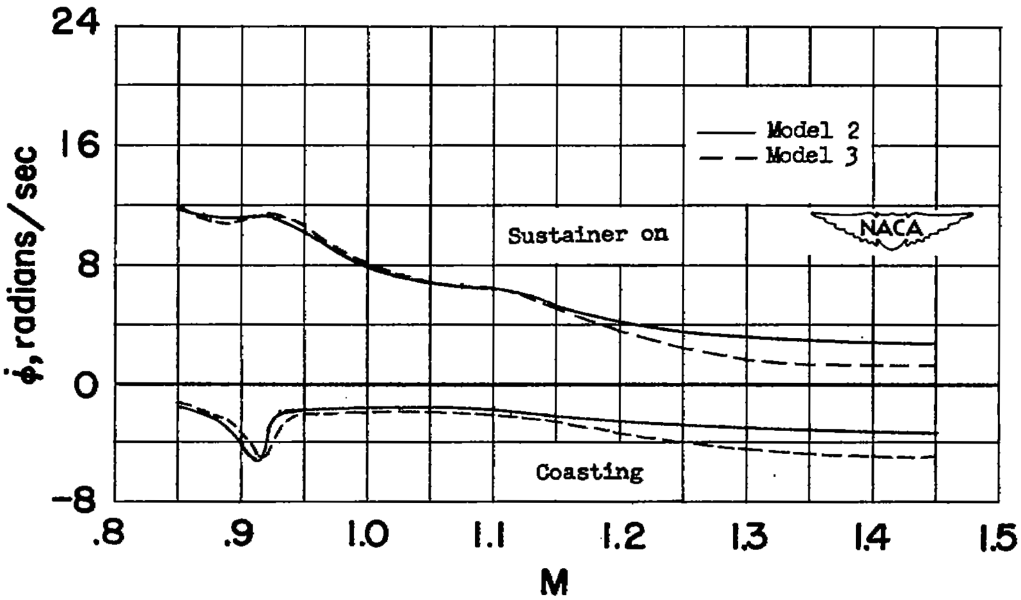


Figure 2.- Variation of test Reynolds number, based on a chord of 8 inches, with Mach number.

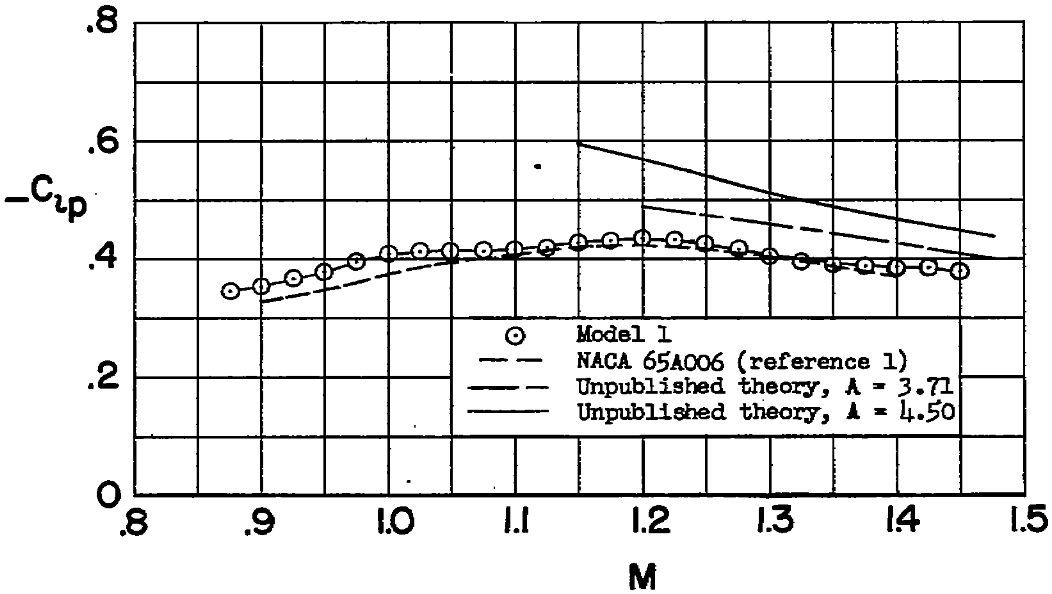


(a) NACA 65-006 airfoil section.

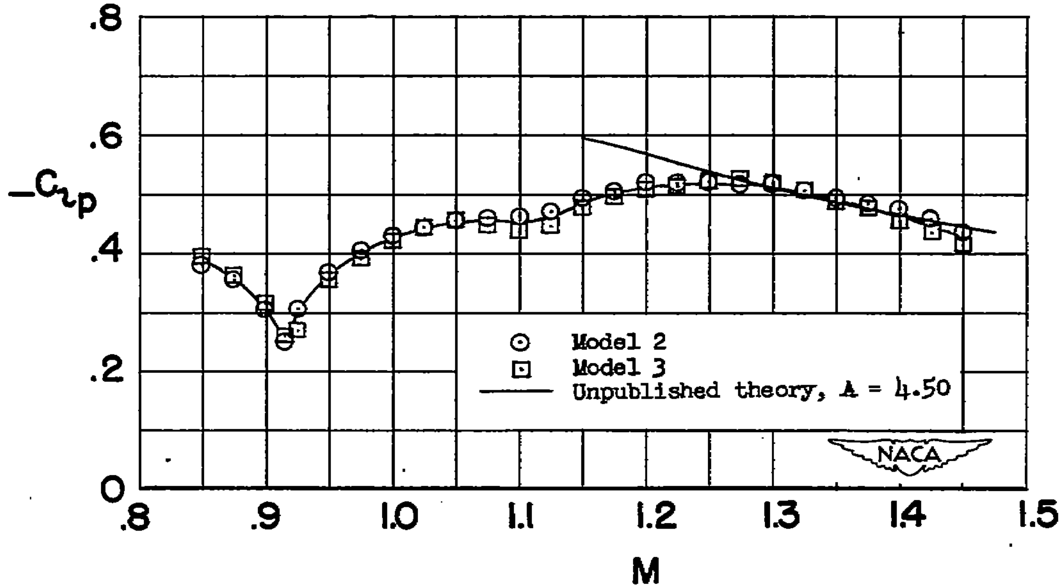


(b) Double-wedge airfoil section.

Figure 3.- Variation of rolling velocity with Mach number.

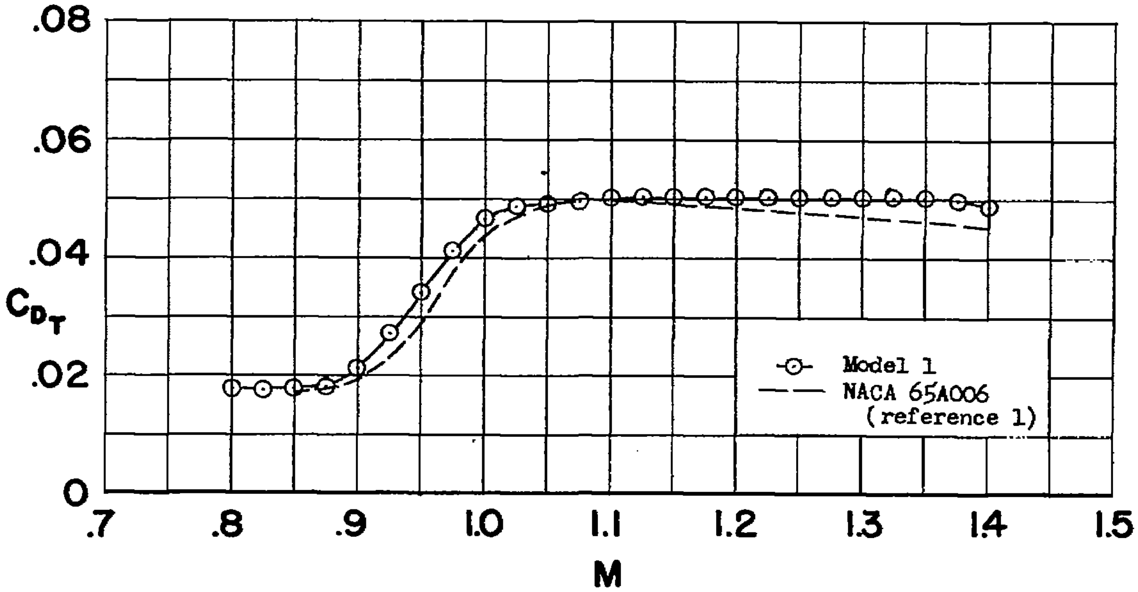


(a) NACA 65-006 airfoil section.

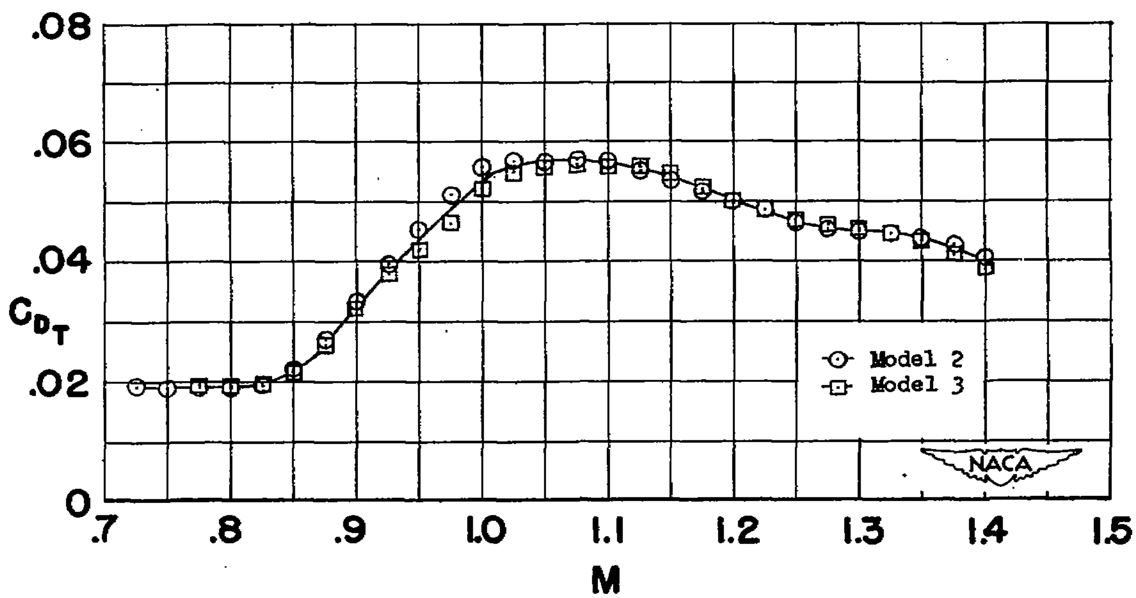


(b) Double-wedge airfoil section.

Figure 4.- Variation of C_{l_p} with Mach number.



(a) NACA 65-006 airfoil section.



(b) Double-wedge airfoil section.

Figure 5.- Variation of total-drag coefficient with Mach number.

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